



1961

# Iron-Cemented Drift in Logan County, North Dakota

John W. Bonneville

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IRON-CEMENTED DRIFT  
in  
LOGAN COUNTY, NORTH DAKOTA

A Paper  
Presented to  
the Faculty of the Department of Geology  
University of North Dakota

Geology 500

by  
John William Bonneville  
January, 1961

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ABSTRACT

In south-central Logan County, North Dakota, west of the Burnstad or Altamont Moraine is exposed a well indurated-limonite-goethite cemented glacial drift. The writer believes the origin of the cementing material to be similar to that of most bog-iron ores, and that this cement accumulated during a pre-Wisconsin interglacial age.

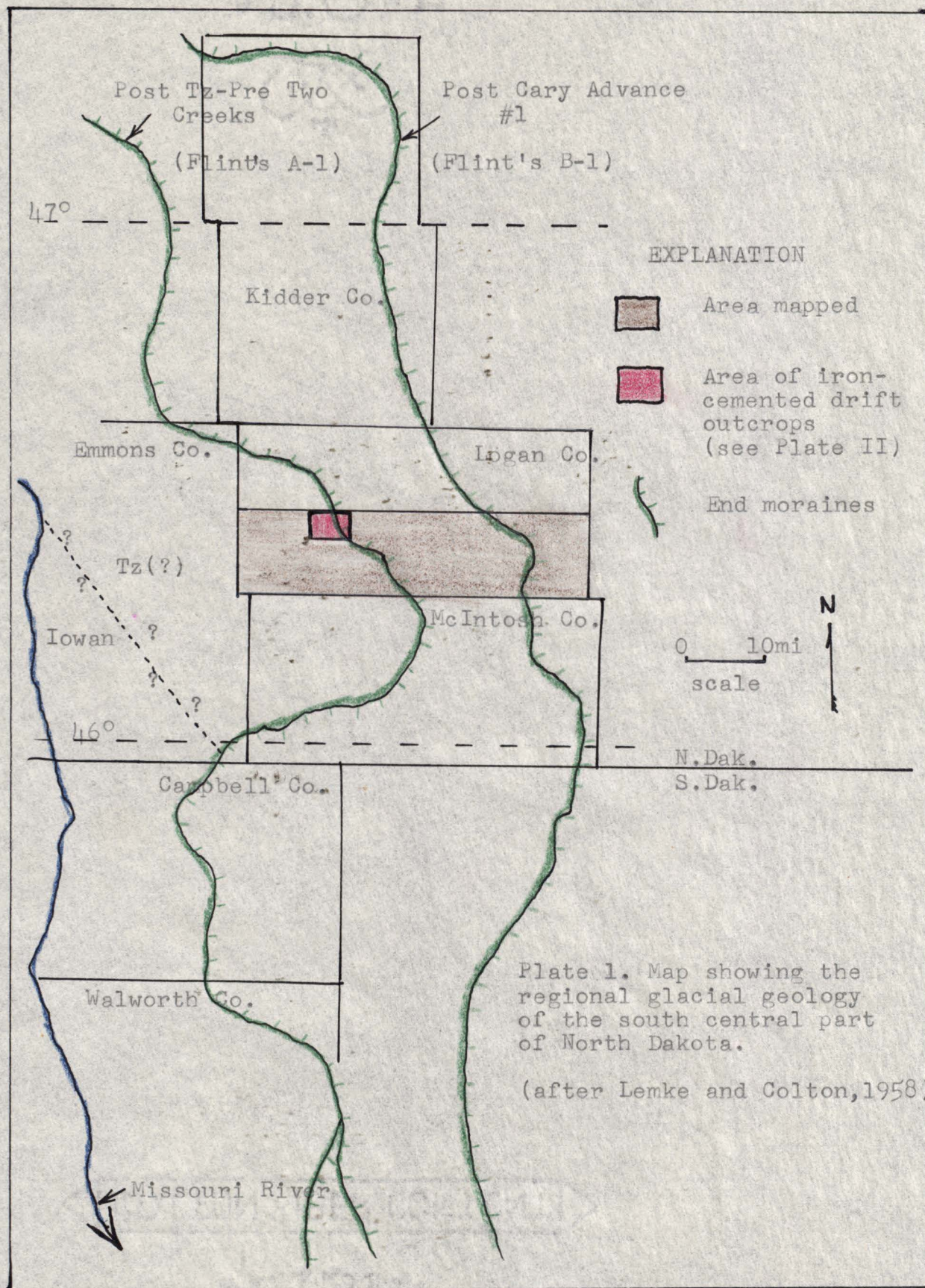
The glacial drift directly overlying the iron-cemented drift has previously been assigned to the Tazewell (?) sub-age; however, the writer believes it to be Iowan in age. If this is proven to be true, by  $C_{14}$  datings now in process, the iron-cemented drift is pre-Wisconsin in age, the first such deposit reported from this part of North Dakota.

A possible sequence of events is offered to explain the entire Pleistocene history of the outcrop area.

INTRODUCTION

GENERAL-A number of interesting deposits of iron-cemented glacial drift were found by the writer while mapping the surficial geology of southern Logan County, North Dakota. (see plate I) An interpretation as to the origin and geologic significance of this deposit was thought important in the overall regional glacial history of the area because (1.) similar deposits have not been reported from the region thus far, (2.) the significant occurrence of  $C_{14}$  datable material underlying one outcrop, and (3.) a pre-Wisconsin age for the deposit is suggested by correlating the overlying drift with type Iowan drift in Iowa.







LOCATION, TOPOGRAPHY, AND PHYSIOGRAPHY-The iron-cemented glacial drift was found in seven outcrops in three different locations in T. 134 N., R. 71 W., and <sup>R.</sup> 72 W. (see plate II) All exposures of this drift were found in areas of bedrock topography, with a local relief of up to 150 feet. The topography is largely due to the headward erosion of the tributary streams of Beaver Creek (see map) cutting into the thick weakly-consolidated Cretaceous Fox Hills sandstones which underlie the entire area. In most places only thin patches of glacial till, gravel, or boulders remain on the divides eroded from bedrock. At the present time, the well-indurated iron-cemented drift forms resistant caps on bedrock highs. This topography, including the integrated drainage, is much older than the topography one or two miles to the east in the Beaver Lake area. In that area the poorly developed drainage, thick drift, young glacial features, and the well developed Burnstad end moraine, show that a more recent ice advance covered this area. (Flint's A-1 advance, Lemke and Colton's Post-Tazewell (?) -pre-Two Creeks drift), (see plate I).

FIELD AND LABORATORY WORK-A thorough field examination of Logan County revealed a total of seven outcrops showing the iron-cemented drifts. Tracing of this drift under younger drift in two localities was possible, but drill holes in adjacent areas of thicker drift were not available for additional study.

Lithologic descriptions and stratigraphic relations were noted in the field, and 100 lbs. of samples from the outcrops were brought back to the laboratory for examination. Twelve



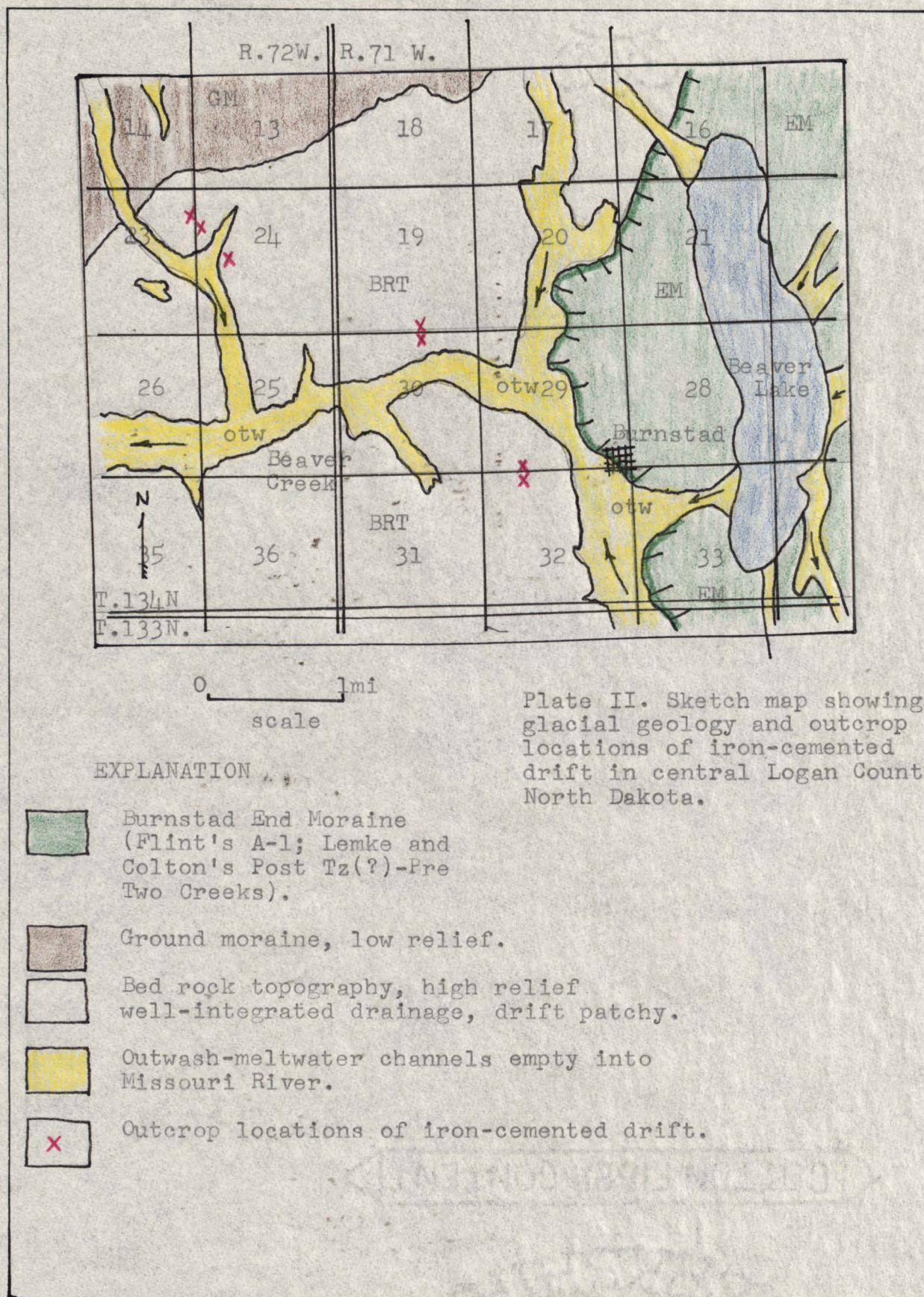


Plate II. Sketch map showing glacial geology and outcrop locations of iron-cemented drift in central Logan County North Dakota.



thin sections were made from different samples for a microscopic study of the sediment. Stannous chloride was used to dissolve the limonite-goethite cement from the drift for residue analysis.

#### STRATIGRAPHY AND DETAILED DESCRIPTION OF THE IRON-CEMENTED DRIFT

MACRO DESCRIPTION-The iron-cemented drift is a clastic sediment, (probably glacial outwash), with a heavy chemically or bio-chemically precipitated limonite-goethite ( $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ ) cement. It is massive to weakly stratified as most glacial gravels are, and it has numerous molds of the more soluble pebbles which have been completely leached out of the cementing material. The molds, which probably were carbonate grains, have not been filled with cementing material, but there is evidence of some early surficial replacement of the carbonate before more extensive leaching removed them. The texture is rudaceous to arenaceous with most beds being conglomeratic. The sorting is usually poor. The entire deposit has been impregnated with precipitated limonite-goethite which has cemented the glacial gravels. Laboratory tests using stannous chloride and HCl showed cementing material constituted an average of 40% by volume, and 55% by weight of the total sample. The permeability and porosity are moderate to high, and the mineral composition is extremely variable. Hand samples show various altered and decomposed metamorphic and igneous rock fragments, cherts, quartz, sands, vein quartz and Cretaceous Fox Hills bedrock



pebbles. All carbonates, or calcareous shales such as the Pierre shale have been completely leached out leaving the hollow molds. Laboratory tests for manganese and phosphorus were positive, and are suggestive of bog ore deposition of the cementing material. The origin of this deposit will be discussed in detail later in this paper; briefly it involves deposition of the glacial drift in local depressions, solution of iron from surrounding drift and bedrock by surface and ground waters, precipitation of the iron in the swampy depressions as bog-ore. Then drainage of the depressions and leaching of the carbonates from the iron-cement drift occurred. Using Pettijohn's (1957, p. 255) classification, this deposit could be termed a reddish-brown ferruginous polymictic orthoconglomerate. A typical outcrop is shown in the photo on plate III.

MICRO DESCRIPTION-Micro-photographs taken from four typical thin sections made from samples of iron-cemented drift are shown in plates IV and V. The thin sections made from the deposit in Logan County, North Dakota, were very similar to those described by Moore (1910, p. 531-2) in his studies of bog-ores in Ontario. Moore found in his examination of thin sections that the limonite was in the form of an opaque, reddish-brown mass, which was heterogeneous and had no distinguishing features beyond a porous condition. The limonite mass contained numerous angular to rounded fragments of quartz, feldspars and rock fragments. No definite axes orientation of fragments scattered throughout the limonite groundmass were noted.

Angular silt-sized grains of quartz similar to those





Plate III. Photo of iron-cemented drift outcrop  
area in eastern edge of NE $\frac{1}{4}$  Sec.23,  
T.134N., R.72W., Logan County, North  
Dakota. Pick is 22 inches long.



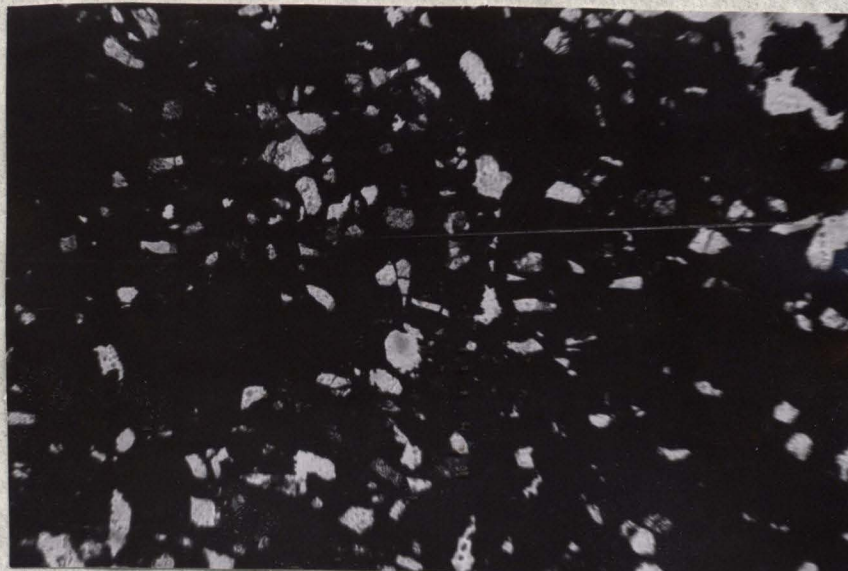
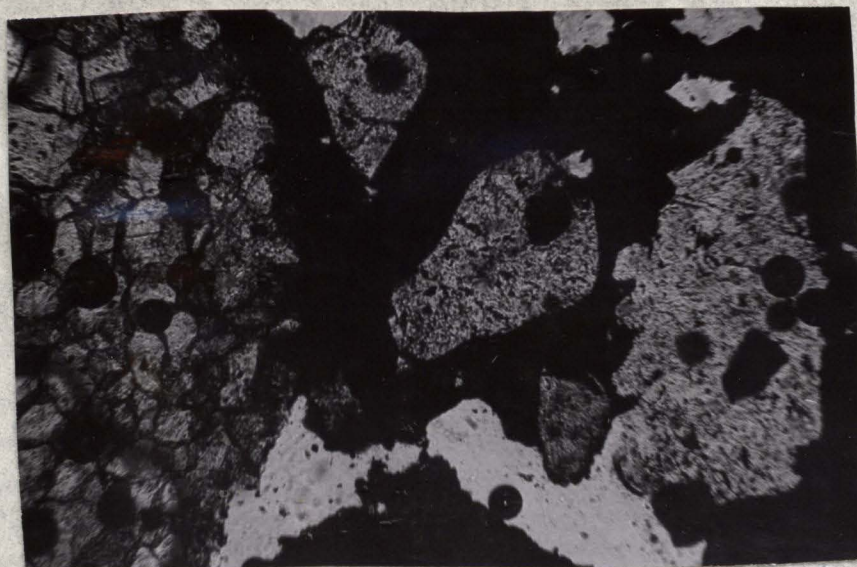


Plate IV. Microphotographs of thin sections of iron-cemented drift.

Fig.1.(Top) Ordinary light, X55, silt-sized grains of quartz, chert, and rare feldspars "floating" in a groundmass of limonite. The uniform size and scattering of the grains is probably due to sheet wash or wind deposition of silt into the marsh while bog ore was forming. The black area is limonite-goethite cement.

Fig.2.(Below) Ordinary light, X55, silt, sand, and pebble-sized grains and rock fragments cemented by limonite. Large grain at left is an igneous rock fragment; the three grains in the middle and right side of the photo are chert grains. The light areas at the bottom and top right are voids. The spherical objects are bubbles, and the black area is limonite cement.





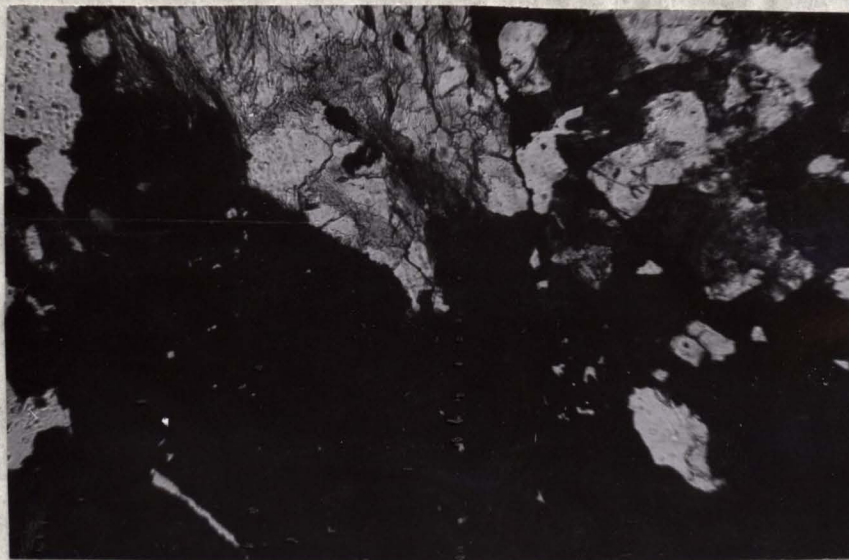
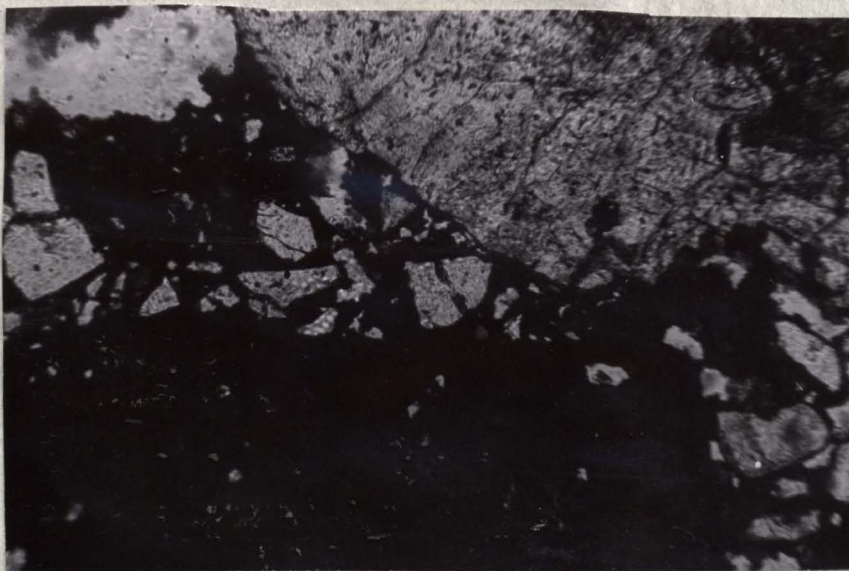


Plate V. Microphotographs of thin sections of iron-cemented drift.

Fig. 1. (Top) Ordinary light, X55, Micaceous metamorphic rock fragment at top of photo with numerous rock fragments and quartz grains at the right. All are cemented together by limonite-goethite (black area). The light areas at the far left are voids.

Fig. 2. (Bottom) Ordinary light, X55. Large chert fragment in the upper right, and the many small angular quartz and chert grains to the left and lower right have been cemented together by limonite-goethite (black area). The light area in the upper left corner is a void.





mentioned by Moore, were observed "floating" in the limonite-geothite cement, and are common in the thin sections from Logan County-these are probably due to sheet wash or aeolean action blowing silt into the open bog during iron deposition.

#### STRATIGRAPHIC POSITION AND TOPOGRAPHIC EXPRESSION

The series of stratigraphic sections shown on plate VI show the relationships of the iron-cemented drift to the overlying and underlying sediments in the outcrop areas. Plate VII shows a composite section of the entire county.

The iron-cemented drift forms a thin resistant cap on bedrock highs where post-glacial erosion has dissected the area. In one locality (see plate VI) the deposit is underlain by 0-3' of gray to black peaty silt, this contact is a sharp one. (see plate VI and plate VIII) This silt has numerous carbonized plant remains which were collected and sent to the U.S. Geological Survey in Washington, D.C., for  $C_{14}$  dating. If this material is within datable range, it will help decipher the glacial history of the area.

The most important outcrop area is that of fig. 4, plate VI, where Cretaceous Fox Hills bedrock is directly overlain by the iron-cemented drift, which is in turn overlain by a gray to light brown unleached till. The contact is sharp with no loess, soil zone, or lag of pebbles at the contact. No other till contacts of other ages in the area have distinctive separating deposits either.



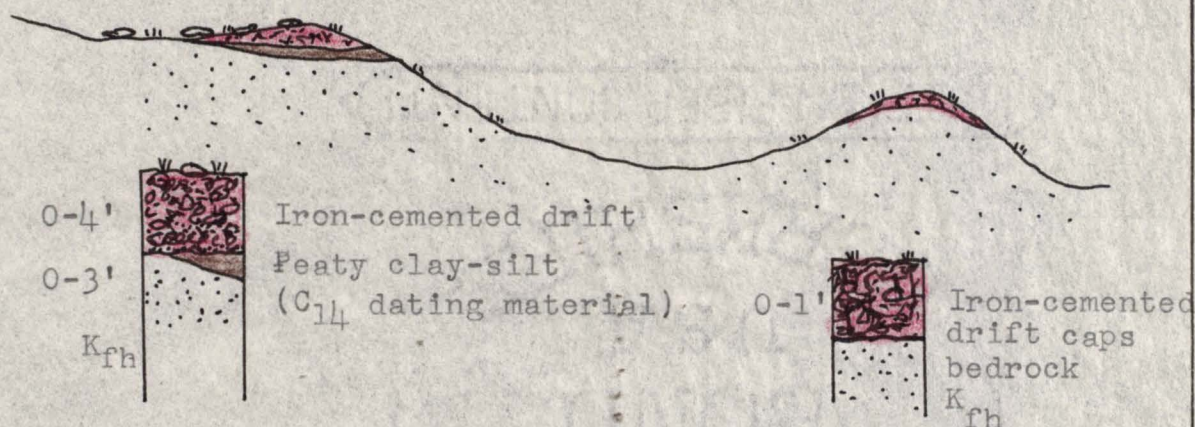


Fig. 1. Section at the west edge of NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W.

Fig. 2 Section at the south edge of the NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W.

Fig. 3. Section at road cut at the north edge of the NW $\frac{1}{4}$  Sec. 30, T.134N., R.71W. This area may have been near the edge of the bog area where the accumulation of limonite was intermittent (the limonite is in streaks).

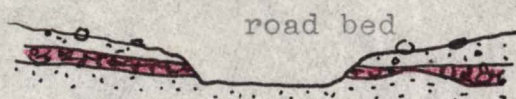
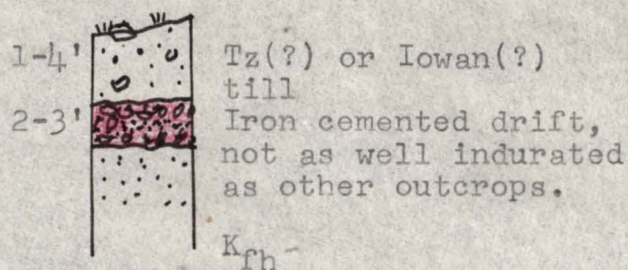


Fig. 4. Section just west of Burnstad where iron-cemented drift crops out on both sides of the road. SW $\frac{1}{4}$  Sec. 29, T.134N. R.71W. Tz(?) or Iowan(?) drift overlies it here.

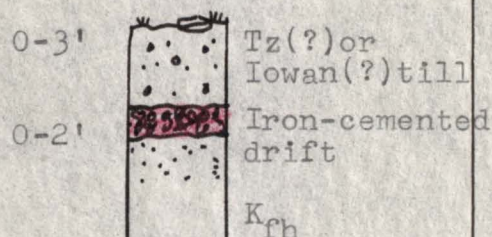


Plate VI. Sketches showing stratigraphic sections and field relationships of the iron-cemented drift in Logan County, North Dakota.



W

E

Youngest drift in the area is Flint's B-1 Streeter Moraine (second Mankato)

The prominent Altamont Moraine is Flint's A-1 (first Mankato) Burnstad Moraine

Napoleon drift sheet  
Tz(?)  
Iowan(?)

Iron-cemented drift

Peaty clay silt

Fox Hills ss.

(Not to scale)

Plate VII. Composite section showing the stratigraphic relations of all the Pleistocene deposits found in the central part of Logan County, North Dakota.





Plate VIII. Photograph of outcrop of iron-cemented drift underlain by peaty clay-silt. The sharp contact can be seen on the photo. This photo was taken facing east at the western edge of the NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W., in Logan County, North Dakota. (See Plate II for location)

In these outcrops the iron-cemented drift forms resistant caps on the erosional divides.



## AGE OF THE IRON-CEMENTED DRIFT

The age of the entire drift sheet west of the end moraine complex known as the Altamont or Max Moraine in this area, has long been in controversy. This drift sheet is herein called the Napoleon drift in Logan County. Todd (1914), referred to it as Nebraskan or Kansan in age; Leonard (1916, p. 532), tentatively referred to the boulders lying on bedrock as Kansan(?) south of the Missouri River, but the drift just west of the Altamont Moraine looked younger to him, and the color of the tills looked more like those of Early Wisconsin. Leverett (1917, p. 144), suggested an Illinoian or Iowan age; and Alden (1932, p. 86), after studying the type Iowan in Iowa, concluded that the drift west of the Altamont in North Dakota was not older than Iowan or possibly Illinoian.

The most important reference is that of Flint (1955, p. 78), where he states that in South Dakota this drift is Iowan with some possible Tazewell drift also, based on tracing around the west side of the James Lobe from the type area in northeastern Iowa.

Continued tracing on aerial photos from the South Dakota border north through McIntosh County into Logan County (only 24 miles) shows the same drift. Lemke and Colton (1958, p. 47), assigned a Tazewell (?) age to the drift, but this assignment is not supported by field evidence in the writer's opinion. In the field, lithologic and topographic expression of the drift in Logan County, and that described from the type Iowan



are very similar. On the for-going criteria, the writer believes the Napoleon drift in Logan County is very probably Iowan in age, with some patches of pre-Napoleon drift found in a few locations underlying it. The iron-cemented drift is such a deposit. The C<sub>14</sub> dating now in progress from the previously mentioned peaty silt bed, and another sample taken from peat in the Napoleon drift itself in northern Logan County should help prove or disprove this. If the Napoleon drift is proved to be Iowan in age, the underlying iron-cemented drift would then be pre-Iowan or pre-Wisconsin in age. The deposition of the iron and the leaching of the carbonate pebbles, then, probably took place during the Sangamon or an earlier inter-glacial age.

#### POSSIBLE ORIGINS OF IRON-CEMENTED DEPOSITS

GENERAL-The major part of the iron-cementing material in the deposits studied was limonite-goethite. These minerals in sedimentary rocks are most characteristic of bog iron-ores. Bog ore is composed principally of an earthy mixture of yellow to dark-brown ferric hydroxides, mainly goethite.

Lake and bog iron ores have been described from Ontario, Quebec, Sweden, Siberia, the eastern United States, and in Washington, but are especially abundant in glaciated northern regions of North America, Europe and Asia. In these areas percolating waters dissolve iron from the glacial drift with the aid of organic and carbonic acids. The iron is carried in solution as soluble carbonate, sulphate, or combined with organic acids. The iron may then be precipitated chemically or



biologically in marshes, peat bogs or other shallow surface depressions (Hurlbut, 1941, p. 206 and Harder, 1919, p. 52). Chemical precipitation takes place either by removal of the solvents by reaction by other materials in solution, or by oxidation. It is generally agreed that plants and bacteria are the chief agents in producing the chemical action in the formation of bog iron. "Iron bacteria" feed on the organic acids which have helped dissolve the iron, this forces the iron to be precipitated in the form of limonite. In other cases the bacteria or algae extract iron for their life processes and sheath formation. The limonite collects as a thin film on the surface of the water and then sinks or is collected on objects along the shore. When it becomes oxidized near the surface, insoluble limonite results (Moore, 1910, p. 532, and Gruner-1922, p. 457).

FORMS OF BOG ORE DEPOSITS-The common form of bog ore deposits found are horizontally tabular bodies a few feet thick, and red, brown or yellow in color. They are described either as soft or hard-bedded masses, concretions, or as a cement in gravels and sands which the iron-rich solutions have impregnated. The deposits studied by the writer ~~MA~~ thought to be such a porous gravel which has been impregnated by iron-rich waters, with subsequent biochemical precipitation of the limonite-goethite as a cementing material.

IRON SOURCE-The source of the iron which was deposited must have either been derived from the existing glacial drift, or the bed-rock, and most probably from both due to the scarcity of drift. It is the present writer's belief that some of the iron came from



the existing drift, but most of it came from the Cretaceous Fox Hills sandstone which contains many iron-bearing minerals, and is in many places hydrostatically higher than the local depressions in which the iron-cemented drift was formed. This provided ground waters an opportunity to remove iron from the Cretaceous sands, and to carry it to depressions at lower elevations where it was precipitated as bog ore.

#### OTHER OCCURRENCES OF IRON-CEMENTED DRIFT IN NORTH AND SOUTH DAKOTA

Leonard (1916), studied the occurrences of older (pre-Wisconsin?) drift west of the Altamont Moraine in North Dakota. He noted that in most areas the drift was represented almost entirely by gravel and boulders resting directly on bedrock. These gravels and boulders were especially noticeable on the tops of divides and on upland areas which they helped protect from erosion. One particularly significant deposit Leonard (p. 526-527), mentions is a boulder bed on the Missouri River near the mouth of Tobacco Garden Creek in McKinzie County, North Dakota. This glacial deposit is composed of boulders and ferruginous gravel which fills the interstices between the coarser material. The entire deposit is cemented into a firm indurated mass. It is very ferruginous and brown colored from the limonite which forms the cementing material, and in many places the boulders are firmly held by the iron-cement and sand which serve as a matrix in which the boulders are embedded. When they weather out, their shape is preserved in



*you are inconsistent  
in your use of  
present & past  
tenses!*

the matrix. Leonard thought that if there ever were any finer materials in this deposit, they have been carried away leaving only the gravel and boulders which were cemented by the iron of the "surface waters". He thought this boulder bed was Kansan(?) in age, but had no substantial proof of this age assignment.

Leonard's description of this deposit is very similar to those which the author found in Logan County, North Dakota. Both deposits are west of the outermost, or Altamont<sup>-MAX</sup> Moraine, are similar in lithology and in having a heavy, firm limonite cement, and both are basal glacial drift deposits overlying bedrock. Probable age assignment of the iron-cemented drift of Logan County is discussed later in this paper.

Paulson(1952, p. 29), mentions a possible pre-Wisconsin drift found in drill holes under known Wisconsin-age tills in southern Stutsman County near Streeter, North Dakota. These test holes showed gravel and gravelly till overlying Cretaceous shales. These gravels were up to 91 feet thick, but were discontinuous from one hole to the next. Tan and white clays are common throughout the deposits, with some patches of red oxidized material. Most of the pebbles in the gravels were igneous and metamorphic rather than shales and carbonates which are common in Wisconsin drifts. One test well showed carbonized wood fragments suggesting a possible soil zone on top of older drift. More drill holes in the area and better sampling methods may prove or disprove this, and may also uncover deposits similar to those cropping out in Logan County.

Flint (1955, p. 30), states that pre-Wisconsin (Illinoian)



has been recognized in only a few places west of the Mississippi River. These locations are in southeastern Iowa and southeastern Minnesota. A probable Illinoian drift near Chamberlain, South Dakota, and a till of unknown age underlying Loveland loess in Moody County, are the only other possible pre-Wisconsin deposits known in South Dakota.

In regions outside South Dakota, Flint goes on to state that tills have been differentiated on a basis of weathering. Wisconsin tills are little altered, while pre-Wisconsin tills are considerably altered. Conversion of a till to a gumbotill therefore indicates the till is pre-Wisconsin. On page 31, Flint states that accumulations of red iron oxide have been found characteristically developed in soil profiles formed during the Sangamon and other interglacial ages. In accordance with this general relationship, a till altered to a reddish soil in South Dakota is considered pre-Sangamon in age with a high degree of probability.

Whether this can be used as a valid criteria to determine or even suggest a pre-Wisconsin age is at least questionable. The writer has seen reddish altered soils and outwash deposits of late Wisconsin age stained completely red with iron oxides. The age determination of the iron-cemented drift in Logan County, North Dakota, is not based on Flint's above mentioned theory, even though it is believed that this drift is pre-Wisconsin in age.

#### INFERENCE AND CONCLUSIONS

GENERAL-The similarities in mineralogy, topography, and possible



origin between the iron-cemented drift in Logan County and bog ore deposits reported throughout glaciated areas of North America and other parts of the world lead this writer to believe that the limonite-goethite cementing material was of the same origin. Thin sections of bog ore and the iron-cemented drift show similar relationships also.

The significance of such a deposit located stratigraphically below a till of Iowan(?) age (depending on  $C_{14}$  results), is important in the interpretation of the Pleistocene geology of North Dakota.

Tracing of the Napoleon, (Iowan?), drift of Logan County to type Iowan in Iowa, together with stratigraphic, lithologic, and topographic close similarities to type Iowan are strong evidence that the age proposal of Iowan is correct. The two  $C_{14}$  dates from this drift should help in solving the problem.

If the age of the Napoleon drift is Iowan, the iron-cemented drift under it is pre-Wisconsin, and proves North Dakota was glaciated in pre-Wisconsin time.

The possible sequence of events in the formation of the iron-cemented drift deposits in Logan County is shown and described on plate IX.



## EXPLANATION OF PLATE IX

### STAGE

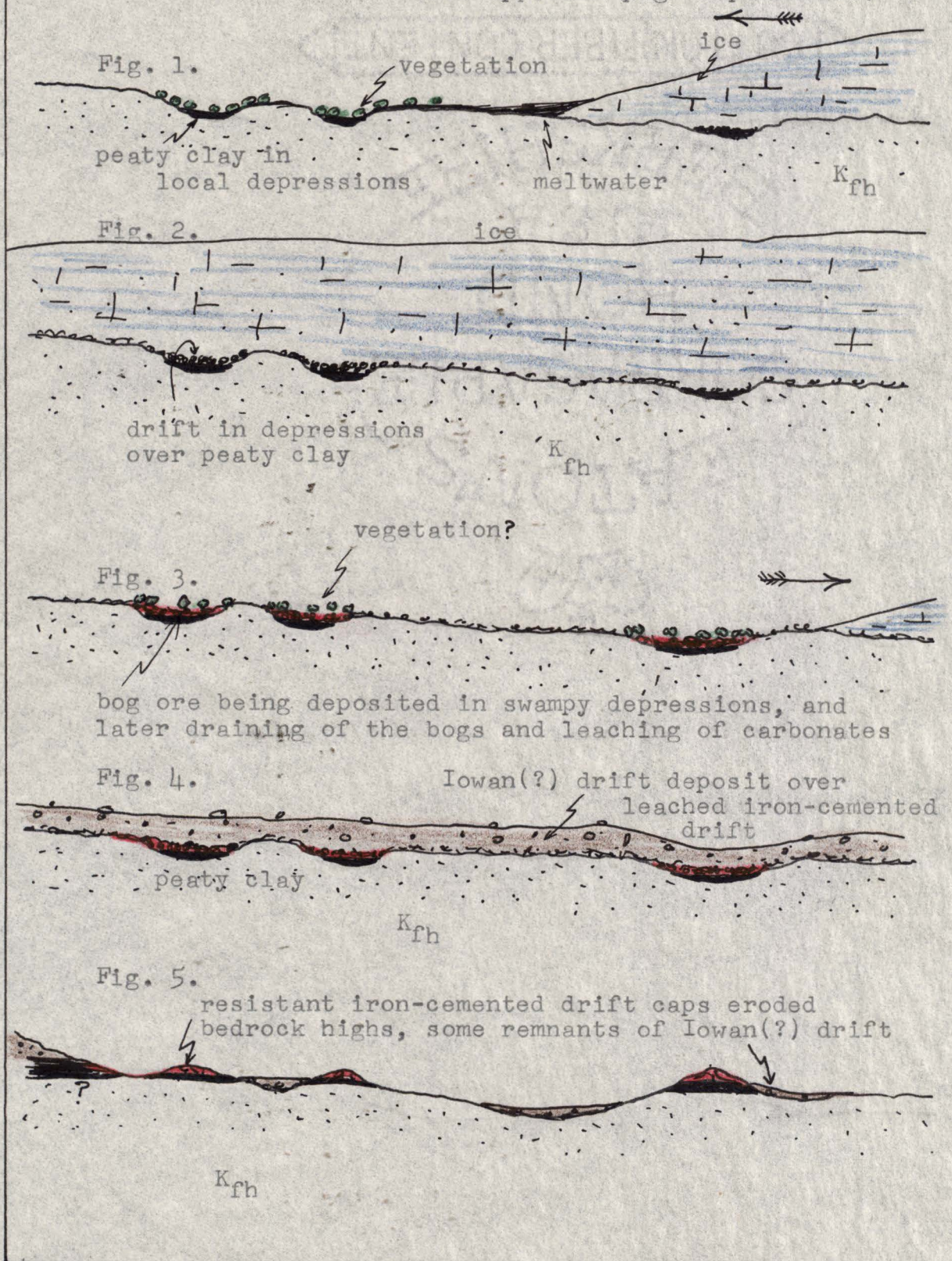
- Fig. 1. Meltwaters filled depressions far ahead of the advancing ice, forming swampy areas. The fines carried by the meltwater together with plant debris such as mosses are deposited contemporaneously in the depressions- this is the peaty clay found at present. Thin non-peaty clays and silts were deposited over the peaty clays in some areas when the ice advanced.
- Fig. 2. The ice overrode the area of swampy bogs, and may have either deposited outwash gravels as it advanced by bottom scraping of the ice, or by normal meltwater deposition either during advance or retreat.
- Fig. 3. The next changes in environment were: retreat of the ice and a return of local swampy conditions, and a high water table. Iron was dissolved from the drift and the Fox Hills sandstone at higher elevations, and was carried to the bogs where it was precipitated as bog ore (limonite and goethite). Precipitation was probably accomplished both chemically and biochemically.

The period of bog ore deposition was during an interglacial age, also during which the bogs were probably drained to due headward erosion of streams with lower base levels. This initiated downward moving ground waters and the ultimate complete leaching of carbonate materials in the iron-cemented glacial gravels, leaving molds of these pebbles in the cemented drift. These voids are not filled with iron-cement which shows the leaching occurred after cementation ceased due to draining of the bogs.

- Fig. 4. A later readvance of the ice (Iowan(?)) left a thin deposit of drift over the leached iron-cemented drift patches.
- Fig. 5. Subsequent erosion since the Iowan(?) until the present time, about 35-40,000+ years, has left only the more resistant indurated iron-cemented drift capping the Cretaceous Fox Hills bedrock, with only remnants of thin easily eroded Iowan(?) drift overlying it in this dissected area. Parts of the region immediately to the north have not been eroded as extensively, and still have the Iowan(?) drift covering bedrock in most places. No drill holes are yet available to prove the existence of additional iron-cemented drift deposits under the younger drift.



Plate IX Possible sequence of events.  
(see opposite page explanation)





## REFERENCES

(\*)Those indicated are referred to in the text.

- (\*)Alden, W.C., 1932, Physiography and Glacial Geology of Eastern Montana and Adjacent Areas: U.S. Geol. Survey Prof. Paper 174, p. 1-133.
- Carozzi, A.V., 1960, Microscopic Sedimentary Petrography: John Wiley & Sons Inc., New York, p. 45.
- Emmons, S.F., 1913, Ore Deposits: The Institute, New York, p. 694, 695.
- (\*)Flint, R.F., 1955, Pleistocene Geology of Eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.
- Goldstein, A.Jr., 1948, Cementation of Dakota Sandstones of the Colorado Front Range: Jour. Sed. Petrology, v. 18, p. 108-125.
- (\*)Gruner, J.W., 1922, The Origin of Sedimentary Iron Formations: Econ. Geology, v. 17, p. 407-458.
- (\*)Harder, E.C., 1919, Iron Depositing Bacteria and Their Geologic Relation: U.S. Geol. Survey Prof. Paper 113, 89p.
- \*Hurlbut, C.S., Jr., 1941, Dana's Manual of Mineralogy: John Wiley & Sons Inc., New York, p. 205-208.
- Lemke, R.W., and Colton, R.B., 1957, Glacial Map of North Dakota: unpublished.
- (\*)\_\_\_\_\_, 1958, Summary of the Pleistocene Geology of North Dakota, With Maps in Midwestern Friends of the Pleistocene: North Dakota 9th Ann. Field Conf. Guidebook, p. 41-57.
- (\*)Leonard, A.G., 1916, The Pre-Wisconsin Drift of North Dakota: Jour. Geology, v. 24, p. 521-532.
- (\*)Leverett, Frank, 1917, Glacial Formations of Western United States: Geol. Soc. America Bull., v. 28, p. 144.
- (\*)Moore, E.J., 1910, The Occurrence and Origin of Some Bog Iron Deposits in the District of Thunder Bay, Ontario: Econ. Geology, v. 5, p. 528-538.
- Moore, E.S., and Maynard, J.E., 1929, Solution, Transportation and Precipitation of Iron and Silica: Econ. Geology, v. 24, p. 272-303.
- \*Paulson, Q.F., 1952, Geology and Occurrence of Ground Water in The Streeter Area, Stutsman, Logan and Kidder Counties, North Dakota: North Dakota Ground Water Studies, no. 20, 73p.



\*Pettijohn, F.J., 1957, Sedimentary Rocks: Harper and Brothers,  
New York, 718 p.

Swineford, A., 1947, Cemented Sandstones of Dakota and Kiowa  
Formations in Kansas: State Geol. Survey Kansas Bull.  
70, part 4, p. 53-104.

Waldschmidt, W.A., 1941, Cementing Materials in Sandstones  
and their Probable Influence on Migration and Accum-  
ulation of Oil and Gas: Am. Assoc. Petroleum Geol.  
Bull., v.25, p.1839-1879.



IRON-CEMENTED DRIFT  
in  
LOGAN COUNTY, NORTH DAKOTA

A Paper  
Presented to  
the Faculty of the Department of Geology  
University of North Dakota

Geology 500

by  
John William Bonneville  
January, 1961

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ABSTRACT

In south-central Logan County, North Dakota, west of the Burnstad or Altamont Moraine is exposed a well indurated-limonite-goethite cemented glacial drift. The writer believes the origin of the cementing material to be similar to that of most bog-iron ores, and that this cement accumulated during a pre-Wisconsin interglacial age.

The glacial drift directly overlying the iron-cemented drift has previously been assigned to the Tazewell (?) sub-age; however, the writer believes it to be Iowan in age. If this is proven to be true, by  $C_{14}$  datings now in process, the iron-cemented drift is pre-Wisconsin in age, the first such deposit reported from this part of North Dakota.

A possible sequence of events is offered to explain the entire Pleistocene history of the outcrop area.

INTRODUCTION

GENERAL-A number of interesting deposits of iron-cemented glacial drift were found by the writer while mapping the surficial geology of southern Logan County, North Dakota. (see plate I) An interpretation as to the origin and geologic significance of this deposit was thought important in the overall regional glacial history of the area because (1.) similar deposits have not been reported from the region thus far, (2.) the significant occurrence of  $C_{14}$  datable material underlying one outcrop, and (3.) a pre-Wisconsin age for the deposit is suggested by correlating the overlying drift with type Iowan drift in Iowa.

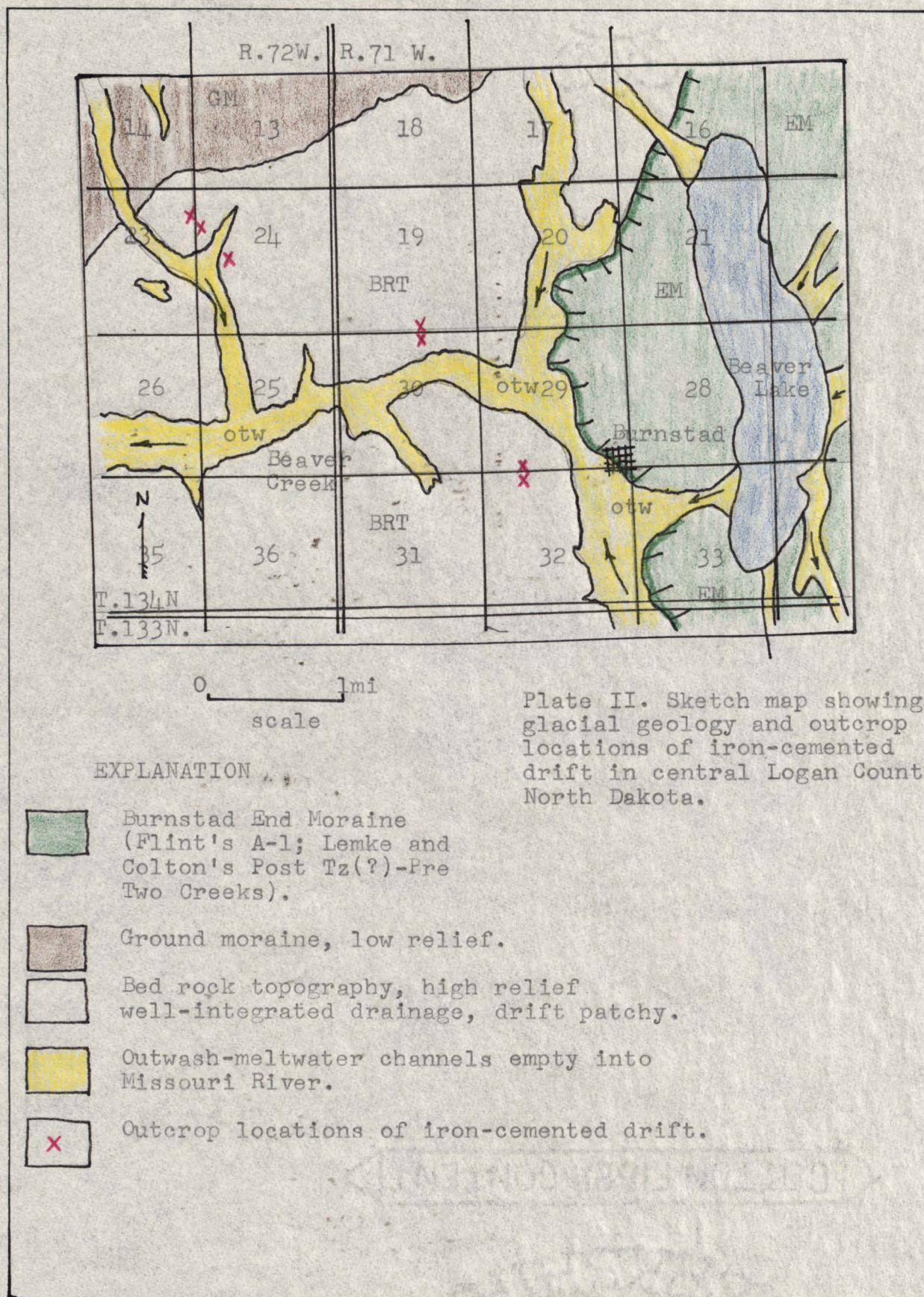


LOCATION, TOPOGRAPHY, AND PHYSIOGRAPHY-The iron-cemented glacial drift was found in seven outcrops in three different locations in T. 134 N., R. 71 W., and <sup>R.</sup> 72 W. (see plate II) All exposures of this drift were found in areas of bedrock topography, with a local relief of up to 150 feet. The topography is largely due to the headward erosion of the tributary streams of Beaver Creek (see map) cutting into the thick weakly-consolidated Cretaceous Fox Hills sandstones which underlie the entire area. In most places only thin patches of glacial till, gravel, or boulders remain on the divides eroded from bedrock. At the present time, the well-indurated iron-cemented drift forms resistant caps on bedrock highs. This topography, including the integrated drainage, is much older than the topography one or two miles to the east in the Beaver Lake area. In that area the poorly developed drainage, thick drift, young glacial features, and the well developed Burnstad end moraine, show that a more recent ice advance covered this area. (Flint's A-1 advance, Lemke and Colton's Post-Tazewell (?) -pre-Two Creeks drift), (see plate I).

FIELD AND LABORATORY WORK-A thorough field examination of Logan County revealed a total of seven outcrops showing the iron-cemented drifts. Tracing of this drift under younger drift in two localities was possible, but drill holes in adjacent areas of thicker drift were not available for additional study.

Lithologic descriptions and stratigraphic relations were noted in the field, and 100 lbs. of samples from the outcrops were brought back to the laboratory for examination. Twelve







thin sections were made from different samples for a microscopic study of the sediment. Stannous chloride was used to dissolve the limonite-goethite cement from the drift for residue analysis.

STRATIGRAPHY AND DETAILED DESCRIPTION OF THE IRON-CEMENTED DRIFT  
MACRO DESCRIPTION-The iron-cemented drift is a clastic sediment, (probably glacial outwash), with a heavy chemically or bio-chemically precipitated limonite-goethite ( $\text{Fe}_2\text{O}_3 \cdot n\text{H}_2\text{O}$ ) cement. It is massive to weakly stratified as most glacial gravels are, and it has numerous molds of the more soluble pebbles which have been completely leached out of the cementing material. The molds, which probably were carbonate grains, have not been filled with cementing material, but there is evidence of some early surficial replacement of the carbonate before more extensive leaching removed them. The texture is rudaceous to arenaceous with most beds being conglomeratic. The sorting is usually poor. The entire deposit has been impregnated with precipitated limonite-goethite which has cemented the glacial gravels. Laboratory tests using stannous chloride and HCl showed cementing material constituted an average of 40% by volume, and 55% by weight of the total sample. The permeability and porosity are moderate to high, and the mineral composition is extremely variable. Hand samples show various altered and decomposed metamorphic and igneous rock fragments, cherts, quartz, sands, vein quartz and Cretaceous Fox Hills bedrock



pebbles. All carbonates, or calcareous shales such as the Pierre shale have been completely leached out leaving the hollow molds. Laboratory tests for manganese and phosphorus were positive, and are suggestive of bog ore deposition of the cementing material. The origin of this deposit will be discussed in detail later in this paper; briefly it involves deposition of the glacial drift in local depressions, solution of iron from surrounding drift and bedrock by surface and ground waters, precipitation of the iron in the swampy depressions as bog-ore. Then drainage of the depressions and leaching of the carbonates from the iron-cement drift occurred. Using Pettijohn's (1957, p. 255) classification, this deposit could be termed a reddish-brown ferruginous polymictic orthoconglomerate. A typical outcrop is shown in the photo on plate III.

MICRO DESCRIPTION-Micro-photographs taken from four typical thin sections made from samples of iron-cemented drift are shown in plates IV and V. The thin sections made from the deposit in Logan County, North Dakota, were very similar to those described by Moore (1910, p. 531-2) in his studies of bog-ores in Ontario. Moore found in his examination of thin sections that the limonite was in the form of an opaque, reddish-brown mass, which was heterogeneous and had no distinguishing features beyond a porous condition. The limonite mass contained numerous angular to rounded fragments of quartz, feldspars and rock fragments. No definite axes orientation of fragments scattered throughout the limonite groundmass were noted.

Angular silt-sized grains of quartz similar to those





Plate III. Photo of iron-cemented drift outcrop  
area in eastern edge of NE $\frac{1}{4}$  Sec.23,  
T.134N., R.72W., Logan County, North  
Dakota. Pick is 22 inches long.



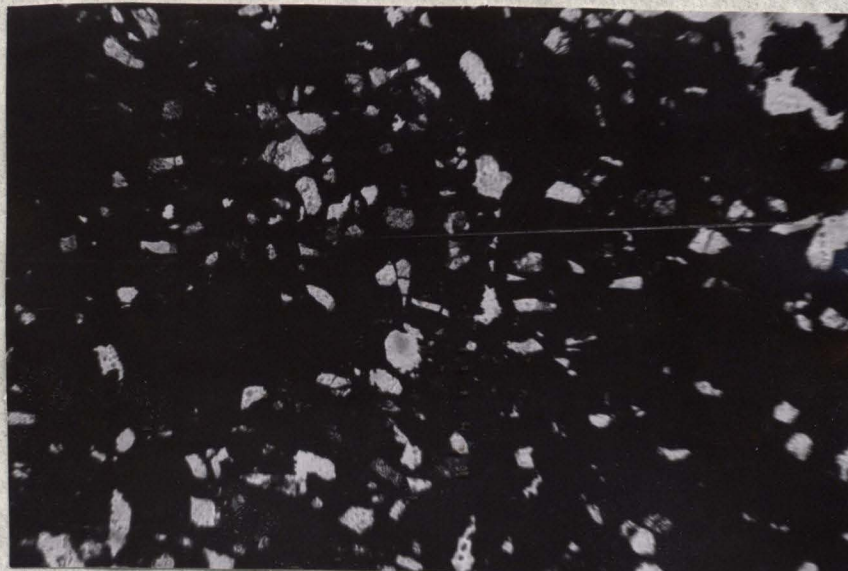
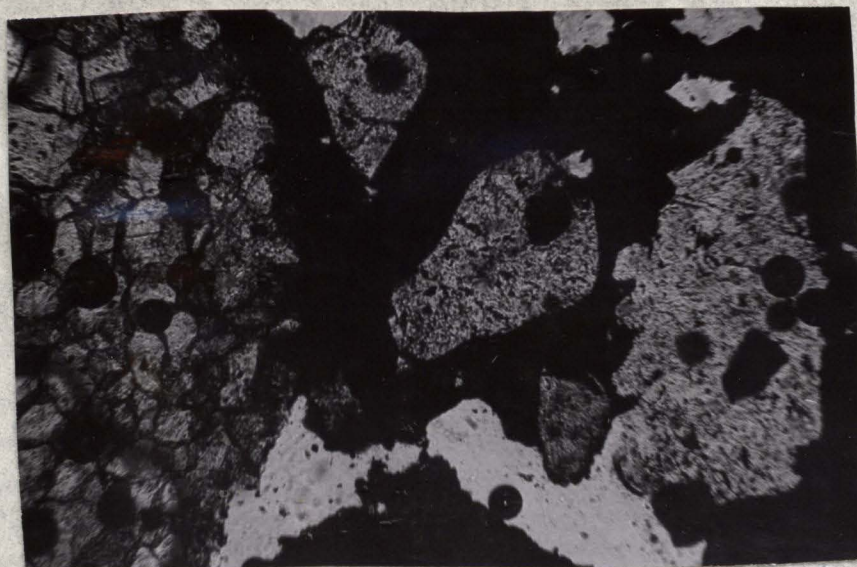


Plate IV. Microphotographs of thin sections of iron-cemented drift.

Fig.1.(Top) Ordinary light, X55, silt-sized grains of quartz, chert, and rare feldspars "floating" in a groundmass of limonite. The uniform size and scattering of the grains is probably due to sheet wash or wind deposition of silt into the marsh while bog ore was forming. The black area is limonite-goethite cement.

Fig.2.(Below) Ordinary light, X55, silt, sand, and pebble-sized grains and rock fragments cemented by limonite. Large grain at left is an igneous rock fragment; the three grains in the middle and right side of the photo are chert grains. The light areas at the bottom and top right are voids. The spherical objects are bubbles, and the black area is limonite cement.





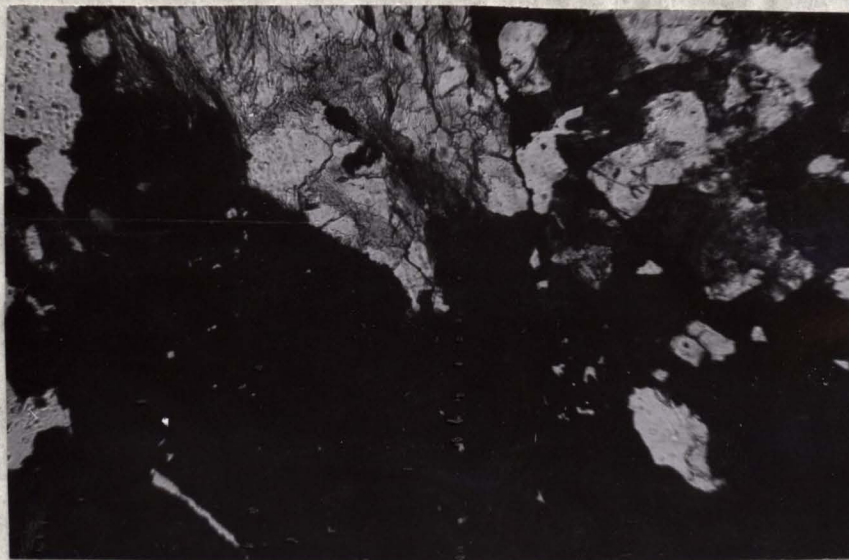
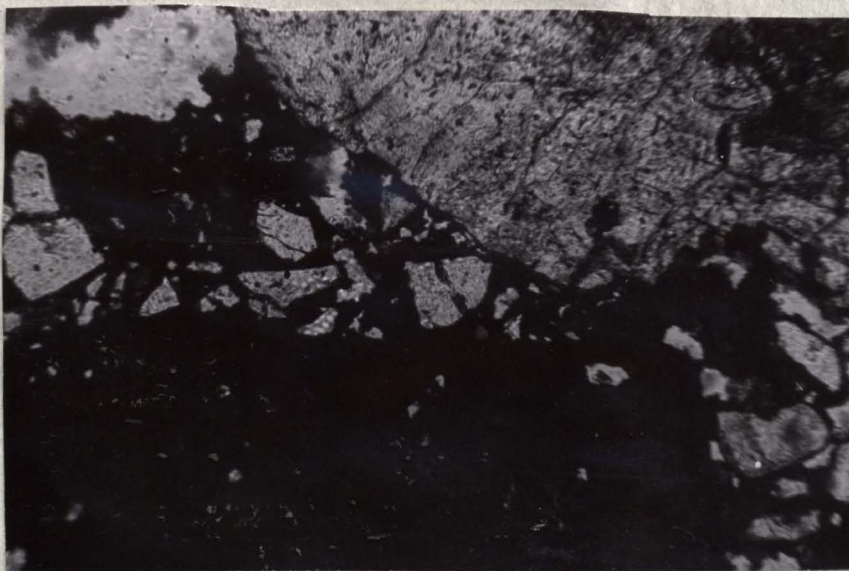


Plate V. Microphotographs of thin sections of iron-cemented drift.

Fig. 1. (Top) Ordinary light, X55, Micaceous metamorphic rock fragment at top of photo with numerous rock fragments and quartz grains at the right. All are cemented together by limonite-goethite (black area). The light areas at the far left are voids.

Fig. 2. (Bottom) Ordinary light, X55. Large chert fragment in the upper right, and the many small angular quartz and chert grains to the left and lower right have been cemented together by limonite-goethite (black area). The light area in the upper left corner is a void.





mentioned by Moore, were observed "floating" in the limonite-geothite cement, and are common in the thin sections from Logan County-these are probably due to sheet wash or aeolean action blowing silt into the open bog during iron deposition.

#### STRATIGRAPHIC POSITION AND TOPOGRAPHIC EXPRESSION

The series of stratigraphic sections shown on plate VI show the relationships of the iron-cemented drift to the overlying and underlying sediments in the outcrop areas. Plate VII shows a composite section of the entire county.

The iron-cemented drift forms a thin resistant cap on bedrock highs where post-glacial erosion has dissected the area. In one locality (see plate VI) the deposit is underlain by 0-3' of gray to black peaty silt, this contact is a sharp one. (see plate VI and plate VIII) This silt has numerous carbonized plant remains which were collected and sent to the U.S. Geological Survey in Washington, D.C., for C<sub>14</sub> dating. If this material is within datable range, it will help decipher the glacial history of the area.

The most important outcrop area is that of fig. 4, plate VI, where Cretaceous Fox Hills bedrock is directly overlain by the iron-cemented drift, which is in turn overlain by a gray to light brown unleached till. The contact is sharp with no loess, soil zone, or lag of pebbles at the contact. No other till contacts of other ages in the area have distinctive separating deposits either.



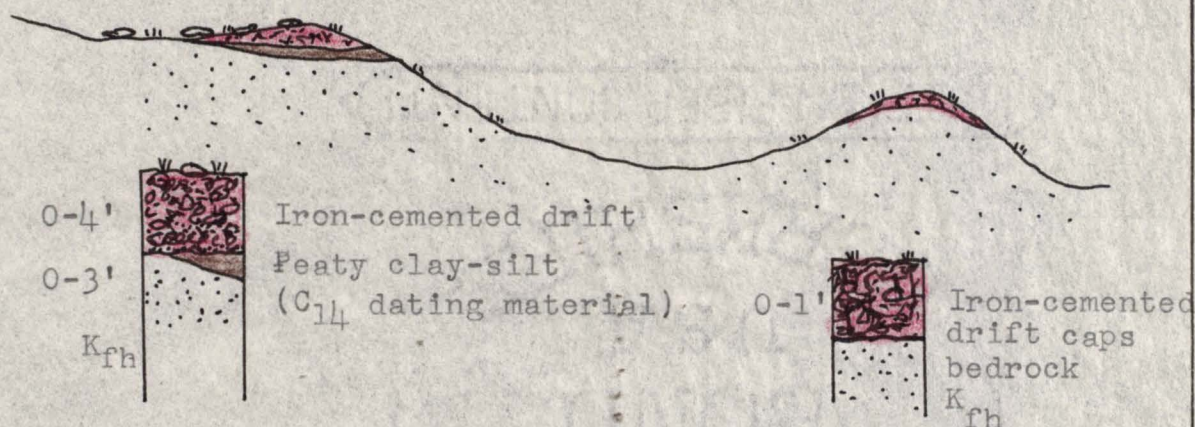


Fig. 1. Section at the west edge of NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W.

Fig. 2 Section at the south edge of the NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W.

Fig. 3. Section at road cut at the north edge of the NW $\frac{1}{4}$  Sec. 30, T.134N., R.71W. This area may have been near the edge of the bog area where the accumulation of limonite was intermittent (the limonite is in streaks).

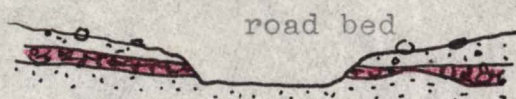
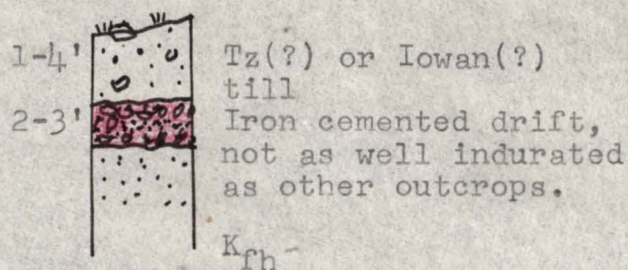


Fig. 4. Section just west of Burnstad where iron-cemented drift crops out on both sides of the road. SW $\frac{1}{4}$  Sec. 29, T.134N. R.71W. Tz(?) or Iowan(?) drift overlies it here.

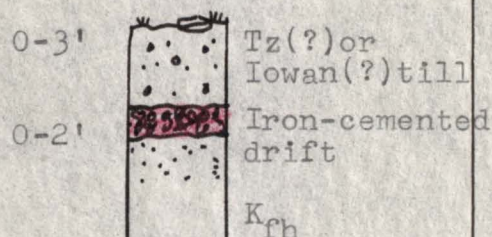


Plate VI. Sketches showing stratigraphic sections and field relationships of the iron-cemented drift in Logan County, North Dakota.



W

E

Youngest drift in the area is Flint's B-1 Streeter Moraine (second Mankato)

The prominent Altamont Moraine is Flint's A-1 (first Mankato) Burnstad Moraine

Napoleon drift sheet  
Tz(?)  
Iowan(?)

Iron-cemented drift

Peaty clay silt

Fox Hills ss.

(Not to scale)

Plate VII. Composite section showing the stratigraphic relations of all the Pleistocene deposits found in the central part of Logan County, North Dakota.





Plate VIII. Photograph of outcrop of iron-cemented drift underlain by peaty clay-silt. The sharp contact can be seen on the photo. This photo was taken facing east at the western edge of the NW $\frac{1}{4}$  Sec. 24, T.134N., R.72W., in Logan County, North Dakota. (See Plate II for location)

In these outcrops the iron-cemented drift forms resistant caps on the erosional divides.



## AGE OF THE IRON-CEMENTED DRIFT

The age of the entire drift sheet west of the end moraine complex known as the Altamont or Max Moraine in this area, has long been in controversy. This drift sheet is herein called the Napoleon drift in Logan County. Todd (1914), referred to it as Nebraskan or Kansan in age; Leonard (1916, p. 532), tentatively referred to the boulders lying on bedrock as Kansan(?) south of the Missouri River, but the drift just west of the Altamont Moraine looked younger to him, and the color of the tills looked more like those of Early Wisconsin. Leverett (1917, p. 144), suggested an Illinoian or Iowan age; and Alden (1932, p. 86), after studying the type Iowan in Iowa, concluded that the drift west of the Altamont in North Dakota was not older than Iowan or possibly Illinoian.

The most important reference is that of Flint (1955, p. 78), where he states that in South Dakota this drift is Iowan with some possible Tazewell drift also, based on tracing around the west side of the James Lobe from the type area in northeastern Iowa.

Continued tracing on aerial photos from the South Dakota border north through McIntosh County into Logan County (only 24 miles) shows the same drift. Lemke and Colton (1958, p. 47), assigned a Tazewell (?) age to the drift, but this assignment is not supported by field evidence in the writer's opinion. In the field, lithologic and topographic expression of the drift in Logan County, and that described from the type Iowan



are very similar. On the for-going criteria, the writer believes the Napoleon drift in Logan County is very probably Iowan in age, with some patches of pre-Napoleon drift found in a few locations underlying it. The iron-cemented drift is such a deposit. The C<sub>14</sub> dating now in progress from the previously mentioned peaty silt bed, and another sample taken from peat in the Napoleon drift itself in northern Logan County should help prove or disprove this. If the Napoleon drift is proved to be Iowan in age, the underlying iron-cemented drift would then be pre-Iowan or pre-Wisconsin in age. The deposition of the iron and the leaching of the carbonate pebbles, then, probably took place during the Sangamon or an earlier inter-glacial age.

#### POSSIBLE ORIGINS OF IRON-CEMENTED DEPOSITS

GENERAL-The major part of the iron-cementing material in the deposits studied was limonite-goethite. These minerals in sedimentary rocks are most characteristic of bog iron-ores. Bog ore is composed principally of an earthy mixture of yellow to dark-brown ferric hydroxides, mainly goethite.

Lake and bog iron ores have been described from Ontario, Quebec, Sweden, Siberia, the eastern United States, and in Washington, but are especially abundant in glaciated northern regions of North America, Europe and Asia. In these areas percolating waters dissolve iron from the glacial drift with the aid of organic and carbonic acids. The iron is carried in solution as soluble carbonate, sulphate, or combined with organic acids. The iron may then be precipitated chemically or



biologically in marshes, peat bogs or other shallow surface depressions (Hurlbut, 1941, p. 206 and Harder, 1919, p. 52). Chemical precipitation takes place either by removal of the solvents by reaction by other materials in solution, or by oxidation. It is generally agreed that plants and bacteria are the chief agents in producing the chemical action in the formation of bog iron. "Iron bacteria" feed on the organic acids which have helped dissolve the iron, this forces the iron to be precipitated in the form of limonite. In other cases the bacteria or algae extract iron for their life processes and sheath formation. The limonite collects as a thin film on the surface of the water and then sinks or is collected on objects along the shore. When it becomes oxidized near the surface, insoluble limonite results (Moore, 1910, p. 532, and Gruner-1922, p. 457).

FORMS OF BOG ORE DEPOSITS-The common form of bog ore deposits found are horizontally tabular bodies a few feet thick, and red, brown or yellow in color. They are described either as soft or hard-bedded masses, concretions, or as a cement in gravels and sands which the iron-rich solutions have impregnated. The deposits studied by the writer ~~MA~~ thought to be such a porous gravel which has been impregnated by iron-rich waters, with subsequent biochemical precipitation of the limonite-goethite as a cementing material.

IRON SOURCE-The source of the iron which was deposited must have either been derived from the existing glacial drift, or the bed-rock, and most probably from both due to the scarcity of drift. It is the present writer's belief that some of the iron came from



the existing drift, but most of it came from the Cretaceous Fox Hills sandstone which contains many iron-bearing minerals, and is in many places hydrostatically higher than the local depressions in which the iron-cemented drift was formed. This provided ground waters an opportunity to remove iron from the Cretaceous sands, and to carry it to depressions at lower elevations where it was precipitated as bog ore.

#### OTHER OCCURRENCES OF IRON-CEMENTED DRIFT IN NORTH AND SOUTH DAKOTA

Leonard (1916), studied the occurrences of older (pre-Wisconsin?) drift west of the Altamont Moraine in North Dakota. He noted that in most areas the drift was represented almost entirely by gravel and boulders resting directly on bedrock. These gravels and boulders were especially noticeable on the tops of divides and on upland areas which they helped protect from erosion. One particularly significant deposit Leonard (p. 526-527), mentions is a boulder bed on the Missouri River near the mouth of Tobacco Garden Creek in McKinzie County, North Dakota. This glacial deposit is composed of boulders and ferruginous gravel which fills the interstices between the coarser material. The entire deposit is cemented into a firm indurated mass. It is very ferruginous and brown colored from the limonite which forms the cementing material, and in many places the boulders are firmly held by the iron-cement and sand which serve as a matrix in which the boulders are embedded. When they weather out, their shape is preserved in



*you are inconsistent  
in your use of  
present & past  
tenses!*

the matrix. Leonard thought that if there ever were any finer materials in this deposit, they have been carried away leaving only the gravel and boulders which were cemented by the iron of the "surface waters". He thought this boulder bed was Kansan(?) in age, but had no substantial proof of this age assignment.

Leonard's description of this deposit is very similar to those which the author found in Logan County, North Dakota. Both deposits are west of the outermost, or Altamont<sup>-MAX</sup> Moraine, are similar in lithology and in having a heavy, firm limonite cement, and both are basal glacial drift deposits overlying bedrock. Probable age assignment of the iron-cemented drift of Logan County is discussed later in this paper.

Paulson(1952, p. 29), mentions a possible pre-Wisconsin drift found in drill holes under known Wisconsin-age tills in southern Stutsman County near Streeter, North Dakota. These test holes showed gravel and gravelly till overlying Cretaceous shales. These gravels were up to 91 feet thick, but were discontinuous from one hole to the next. Tan and white clays are common throughout the deposits, with some patches of red oxidized material. Most of the pebbles in the gravels were igneous and metamorphic rather than shales and carbonates which are common in Wisconsin drifts. One test well showed carbonized wood fragments suggesting a possible soil zone on top of older drift. More drill holes in the area and better sampling methods may prove or disprove this, and may also uncover deposits similar to those cropping out in Logan County.

Flint (1955, p. 30), states that pre-Wisconsin (Illinoian)



has been recognized in only a few places west of the Mississippi River. These locations are in southeastern Iowa and southeastern Minnesota. A probable Illinoian drift near Chamberlain, South Dakota, and a till of unknown age underlying Loveland loess in Moody County, are the only other possible pre-Wisconsin deposits known in South Dakota.

In regions outside South Dakota, Flint goes on to state that tills have been differentiated on a basis of weathering. Wisconsin tills are little altered, while pre-Wisconsin tills are considerably altered. Conversion of a till to a gumbotill therefore indicates the till is pre-Wisconsin. On page 31, Flint states that accumulations of red iron oxide have been found characteristically developed in soil profiles formed during the Sangamon and other interglacial ages. In accordance with this general relationship, a till altered to a reddish soil in South Dakota is considered pre-Sangamon in age with a high degree of probability.

Whether this can be used as a valid criteria to determine or even suggest a pre-Wisconsin age is at least questionable. The writer has seen reddish altered soils and outwash deposits of late Wisconsin age stained completely red with iron oxides. The age determination of the iron-cemented drift in Logan County, North Dakota, is not based on Flint's above mentioned theory, even though it is believed that this drift is pre-Wisconsin in age.

#### INFERENCE AND CONCLUSIONS

GENERAL-The similarities in mineralogy, topography, and possible



origin between the iron-cemented drift in Logan County and bog ore deposits reported throughout glaciated areas of North America and other parts of the world lead this writer to believe that the limonite-goethite cementing material was of the same origin. Thin sections of bog ore and the iron-cemented drift show similar relationships also.

The significance of such a deposit located stratigraphically below a till of Iowan(?) age (depending on  $C_{14}$  results), is important in the interpretation of the Pleistocene geology of North Dakota.

Tracing of the Napoleon, (Iowan?), drift of Logan County to type Iowan in Iowa, together with stratigraphic, lithologic, and topographic close similarities to type Iowan are strong evidence that the age proposal of Iowan is correct. The two  $C_{14}$  dates from this drift should help in solving the problem.

If the age of the Napoleon drift is Iowan, the iron-cemented drift under it is pre-Wisconsin, and proves North Dakota was glaciated in pre-Wisconsin time.

The possible sequence of events in the formation of the iron-cemented drift deposits in Logan County is shown and described on plate IX.



## EXPLANATION OF PLATE IX

### STAGE

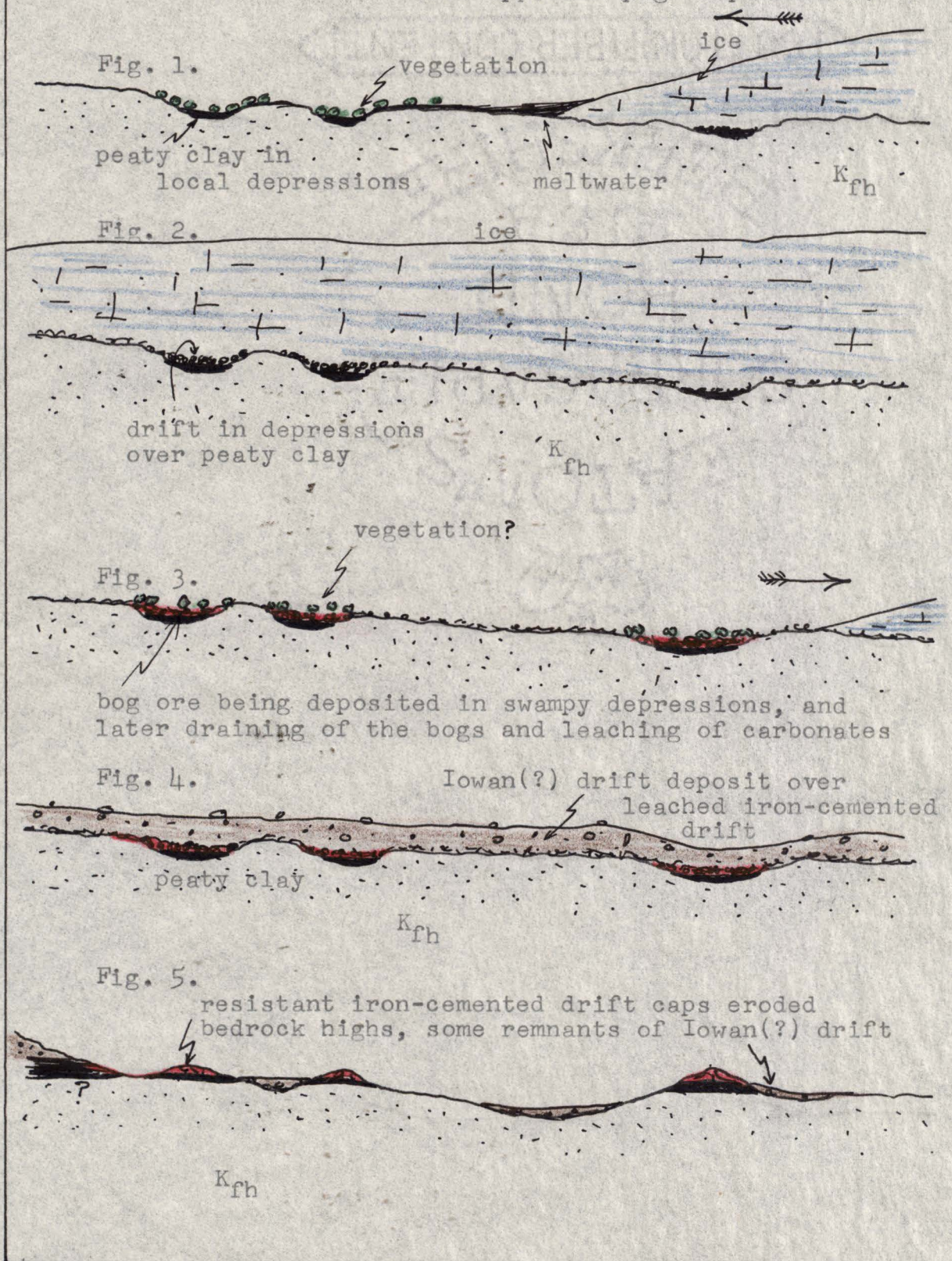
- Fig. 1. Meltwaters filled depressions far ahead of the advancing ice, forming swampy areas. The fines carried by the meltwater together with plant debris such as mosses are deposited contemporaneously in the depressions- this is the peaty clay found at present. Thin non-peaty clays and silts were deposited over the peaty clays in some areas when the ice advanced.
- Fig. 2. The ice overrode the area of swampy bogs, and may have either deposited outwash gravels as it advanced by bottom scraping of the ice, or by normal meltwater deposition either during advance or retreat.
- Fig. 3. The next changes in environment were: retreat of the ice and a return of local swampy conditions, and a high water table. Iron was dissolved from the drift and the Fox Hills sandstone at higher elevations, and was carried to the bogs where it was precipitated as bog ore (limonite and goethite). Precipitation was probably accomplished both chemically and biochemically.

The period of bog ore deposition was during an interglacial age, also during which the bogs were probably drained to due headward erosion of streams with lower base levels. This initiated downward moving ground waters and the ultimate complete leaching of carbonate materials in the iron-cemented glacial gravels, leaving molds of these pebbles in the cemented drift. These voids are not filled with iron-cement which shows the leaching occurred after cementation ceased due to draining of the bogs.

- Fig. 4. A later readvance of the ice (Iowan(?)) left a thin deposit of drift over the leached iron-cemented drift patches.
- Fig. 5. Subsequent erosion since the Iowan(?) until the present time, about 35-40,000+ years, has left only the more resistant indurated iron-cemented drift capping the Cretaceous Fox Hills bedrock, with only remnants of thin easily eroded Iowan(?) drift overlying it in this dissected area. Parts of the region immediately to the north have not been eroded as extensively, and still have the Iowan(?) drift covering bedrock in most places. No drill holes are yet available to prove the existence of additional iron-cemented drift deposits under the younger drift.



Plate IX Possible sequence of events.  
(see opposite page explanation)





## REFERENCES

(\*)Those indicated are referred to in the text.

- (\*)Alden, W.C., 1932, Physiography and Glacial Geology of Eastern Montana and Adjacent Areas: U.S. Geol. Survey Prof. Paper 174, p. 1-133.
- Carozzi, A.V., 1960, Microscopic Sedimentary Petrography: John Wiley & Sons Inc., New York, p. 45.
- Emmons, S.F., 1913, Ore Deposits: The Institute, New York, p. 694, 695.
- (\*)Flint, R.F., 1955, Pleistocene Geology of Eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, 173 p.
- Goldstein, A.Jr., 1948, Cementation of Dakota Sandstones of the Colorado Front Range: Jour. Sed. Petrology, v. 18, p. 108-125.
- (\*)Gruner, J.W., 1922, The Origin of Sedimentary Iron Formations: Econ. Geology, v. 17, p. 407-458.
- (\*)Harder, E.C., 1919, Iron Depositing Bacteria and Their Geologic Relation: U.S. Geol. Survey Prof. Paper 113, 89p.
- \*Hurlbut, C.S., Jr., 1941, Dana's Manual of Mineralogy: John Wiley & Sons Inc., New York, p. 205-208.
- Lemke, R.W., and Colton, R.B., 1957, Glacial Map of North Dakota: unpublished.
- (\*)\_\_\_\_\_, 1958, Summary of the Pleistocene Geology of North Dakota, With Maps in Midwestern Friends of the Pleistocene: North Dakota 9th Ann. Field Conf. Guidebook, p. 41-57.
- (\*)Leonard, A.G., 1916, The Pre-Wisconsin Drift of North Dakota: Jour. Geology, v. 24, p. 521-532.
- (\*)Leverett, Frank, 1917, Glacial Formations of Western United States: Geol. Soc. America Bull., v. 28, p. 144.
- (\*)Moore, E.J., 1910, The Occurrence and Origin of Some Bog Iron Deposits in the District of Thunder Bay, Ontario: Econ. Geology, v. 5, p. 528-538.
- Moore, E.S., and Maynard, J.E., 1929, Solution, Transportation and Precipitation of Iron and Silica: Econ. Geology, v. 24, p. 272-303.
- \*Paulson, Q.F., 1952, Geology and Occurrence of Ground Water in The Streeter Area, Stutsman, Logan and Kidder Counties, North Dakota: North Dakota Ground Water Studies, no. 20, 73p.



\*Pettijohn, F.J., 1957, Sedimentary Rocks: Harper and Brothers,  
New York, 718 p.

Swineford, A., 1947, Cemented Sandstones of Dakota and Kiowa  
Formations in Kansas: State Geol. Survey Kansas Bull.  
70, part 4, p. 53-104.

Waldschmidt, W.A., 1941, Cementing Materials in Sandstones  
and their Probable Influence on Migration and Accum-  
ulation of Oil and Gas: Am. Assoc. Petroleum Geol.  
Bull., v.25, p.1839-1879.



